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COMPUTATION OF LIGHT AND ELECTRIC PARAMETERS OF GAS DISCHARGE XENON, DIRECT CURRENT LAMPS

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ABSTRACT

The results derived from studying the discharge in spherical ultrahigh pressure xenon lamps having a direct current are discussed. Brightness distribution along the discharge axis, dependence of brightness on power and distance between electrodes, and the volt ampere characteristics of xenon lamps are investigated.

Superhigh, gas discharge xenon lamps are finding constantly expanding /5* application in different fields of science and technology requiring an intense light source with a continuous radiation spectrum (Ref. 1, 2, 3 and 4). At the present time spherical, xenon, direct current, ultra high pressure (UHP) xenon lamps are being widely employed, and various requirements are imposed on their light and electrical parameters. In this connection, it is important to make a correct selection of certain initial parameters of the lamp /6 (distance between electrodes, pressure of the filling gas, and lamp power), in order to provide the requisite light and electric characteristics.

A valid calculation of all the light and electric characteristics of the lamp may be made as a function of these initial data, if the dependences

* Note: Numbers in the margin indicate pagination in the original foreign text.

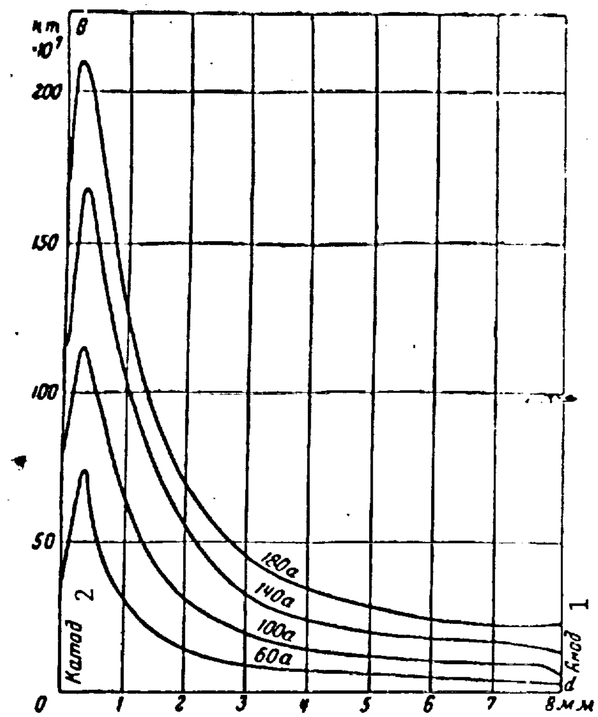

Figure 1.

Set of Curves showing the Brightness Distribution along the Discharge Axis in a UHP, Direct Current Xenon Lamp.

1- Anode; 2- Cathode.

relating all of the indicated lamp parameters are known.

This article presents the results derived from studying the discharge in spherical, UHP xenon lamps having a direct current. These results will enable us to determine these patterns. The studies were performed on special experimental lamps having a power of 9kw, whose construction was proposed by D. A. Goukhberg.

<u>Brightness Distribution along the Discharge Axis.</u>

The center of the cathode spot has the greatest brightness in direct current, xenon lamps. As one recedes from this center along the discharge axis, the brightness first decreases very rapidly, then comparatively slowly (positive discharge column), and then reaches a weakly expressed minimum at the anode. Figure 1 presents a set of curves showing the brightness distribution along the discharge axis for one of the lamps for different current strengths. As the measurements have shown, this brightness distribution along the discharge axis is characteristic for a great number of lamps having very different initial parameters. From this point on, all of the results obtained will pertain to the following changes in the initial parameters: distance between electrodes from 3 - 14 mm; pressure of filling gas from 2 - 9 atm; power from 0.3 - 8 kw.

If a relative system of coordinates is introduced, in which the ratio d/d_o is plotted along the abcissa (where d - distance from the cathode to an arbitrary point from the discharge axis; d_o - distance between electrodes), and the ratio B/B_o is plotted along the ordinate axis (where B - brightness at an arbitrary point at the distance d from the cathode; B_o - brightness at a randomly selected point, where it may be assumed to equal unity) and if curves are compiled in this coordinate system for the brightness distribution along the discharge axis for very different lamps, then - independently of the initial parameters - all of the curves compiled will coincide within the limits of measurement accuracy, forming a certain universal curve for the brightness distribution along the discharge axis. Such a curve is shown in Figure 2.

The brightness at the distance 0.3 d_o from the cathode was assumed to be the unit brightness B_o. The universal curve in the $0.1 \leq d/d_o \leq 1$ range may be approximated by the following expression:

$$B/B_0 = 0{,}38\,(d/d_0)^{-0{,}8}. \qquad (1)$$

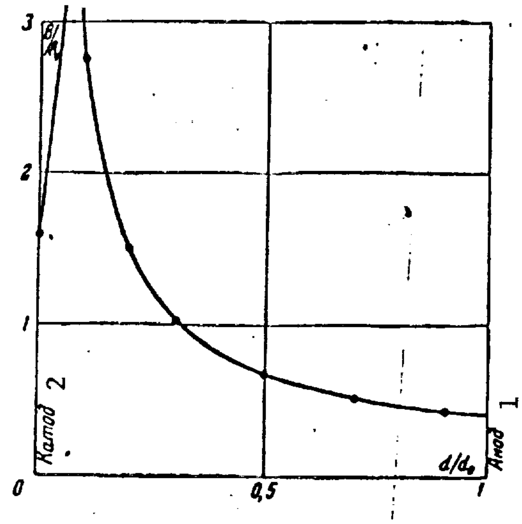

Figure 2.

Universal Curve showing the Brightness Distribution along the Discharge Axis for UHP, Direct Current Xenon Lamps in a Relative Coordinate System.

1- Anode; 2- Cathode

Formula (1) closely approximates the universal curve in the /7 $0.3 \leq d/d_o \leq 1$ section and provides values for the relative brightness in the $0.1 \leq d/d_o \leq 0.3$ section which are somewhat too low. In the $0 \leq d/d_o << 0.07$ range the universal curve is approximated by the line

$$B/B_o = 27\, d/d_o + 1.6. \qquad (2)$$

The brightness maximum lies approximately in the 0.07 d_o region, and - due to the low accuracy with which the brightness at the cathode spot may be measured - its relative brightness was not determined on the universal curve. A special study will be carried out in the future for determining the brightness distribution in the spot, and its relationship with the brightness in other sections of the discharge.

Dependence of Brightness on Power and Distance between Electrodes.

The brightness of a UHP, xenon lamp increases linearly with an increase in power. The dependence of brightness on the distance between electrodes is more complex. G. M. Rokhlin derived a formula for the dependence of brightness on the power of xenon lamps and the distance between electrodes, which he kindly gave to us before it was published:

$$B = A\frac{W}{d_0^2}, \qquad (3)$$

where the brightness B - in 10^7 nits, the power of the lamp W - in kilowatts, the distance between electrodes d_o - in centimeters, and A - the proportionality coefficient.

An analysis of formula (3) shows that, due to the fact that it contains the lamp power W, the proportionality coefficient A cannot be the same for all lamps. Actually, the lamp power W is computed from the discharge power W_p , the total electrode losses, and the loss at the leads. We may usually disregard the latter, since they are small as compared with other values of the power consumed. The discharge power is the effective power, from the point of view of radiation. The electrode losses may differ greatly for two different lamps for one and the same discharge power. Therefore, the same brightness values at a specific point on the discharge axis may be obtained for different lamp powers, which is equivalent to different proportionality coefficients in formula (3). Utilizing the discharge power W_p, instead of the lamp power W, in this formula, we may expect an agreement between the proportionality coefficient A for very different lamps.

Experimental verification of formula (3) has confirmed its validity, and - taking into account the statements presented above - the universality of the

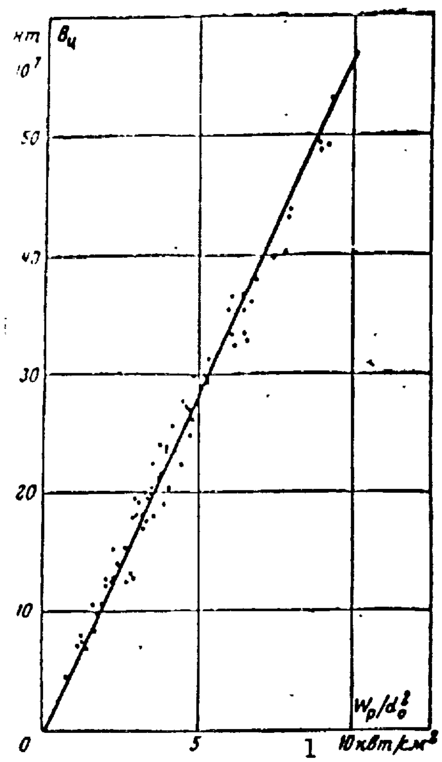

Figure 3.

Dependence of Brightness in the Discharge Geometric Center on the W_p/d^2 Ratio. Solid Line - Average of the Experimental Values.

1- 10 kw/m^2.

proportionality coefficient A. Figure 3 plots the points corresponding to the brightness at the discharge geometric center for different lamps as a function of the W_p/d_0^2 ratio. The line in Figure 3 represents the average value of the experimental quantities. The scatter of the points lies within the limits of error in determining the power and the distance between electrodes. The inclination of the line determines the magnitude of the coefficient A, which equals 5.7 for the brightness in the discharge center.

We may employ formulas (1) and (3) to obtain the expression relating the brightness at any point on the discharge axis - with the exception of the cathode spot - to the discharge power and the distance between the electrodes:

$$B = 3{,}3 \frac{W_p}{d^{0.8} d_0^{1.2}}. \qquad (4)$$

Dependence of Arc Width at the Discharge Center on the Power, Pressure, and Distance Between Electrodes. /8

The so-called halfwidth of the arc is used as the measure of the arc width - i.e., the distance between two points on the transverse cross-section of the discharge projection, at which the brightness decreases twofold as compared with its maximum value in this cross-section. From this point on, for purposes of brevity we shall call the arc halfwidth simply the arc width.

The brightness distribution across the arc in xenon lamps has clearly expressed symmetry with respect to the discharge axis. A study of the transverse brightness distribution in the discharge geometric center for different lamps - whose parameters lie within the limits given above - has shown that the arc width b_o depends linearly on the power, and may be represented as follows

$$b_0 = nW_p + m, \qquad (5)$$

where n and m are certain coefficients. The arc width is expressed in millimeters; the power is expressed in kilowatts.

It has been established that the coefficient n - which is a constant quantity for all lamps - equals approximately 0.37. The coefficient m is a function of the distance between electrodes and a "cold" pressure of the filling gas P_o in a nonoperational lamp. It equals

$$\left.\begin{array}{lll} m = 2{,}9\, d_0/P_0 & \text{for} & 0{,}5 \leqslant d_0/P_0 < 1 \\ m = 0{,}67\, d_0/P_0 + 3{,}2 & \text{for} & 1 < d_0/P_0, \end{array}\right\} \qquad (6)$$

here P_0 is in atmospheres, and d_0 is in millimeters.

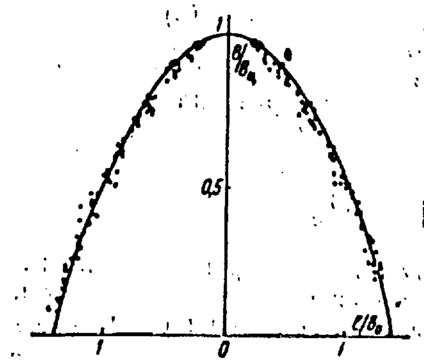

Figure 4.

Brightness Distribution Across the Arc in the Discharge Center of Different Direct Current, UHP Xenon Lamps. Solid Curve Corresponds to the Parabola $y = 1 - 0.5\, x^2$. The Experimental Points were Compiled in a Relative Coordinate System.

The nature of the brightness distribution in the transverse arc cross-section in the discharge center is similar both for different lamps, and for one lamp under different operational regimes. Figure 4 employs a relative coordinate system to plot the points corresponding to the relative brightness values at different points in the arc transverse cross-section for lamps whose parameters lie within the limits stipulated previously. The l/b_0 ratio is plotted along the abcissa axis, where l is the doubled distance from the discharge axis to a given cross-section point, and b_0 is the arc halfwidth. The brightness ratio equaling B/B_μ is plotted along the ordinate axis, where B is the brightness at a given cross-section point, and B_μ is the brightness at the discharge axis (which is maximum for a given cross-section). These points lie on a parabola with a good approximation

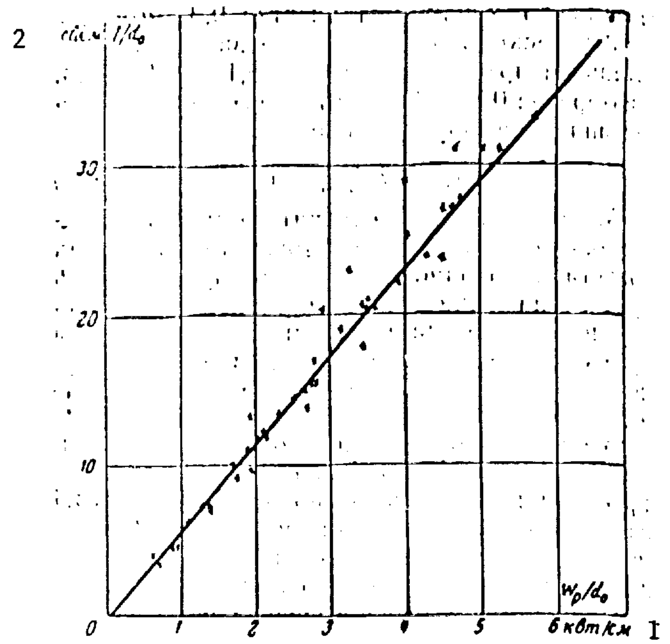

Figure 5.

Dependence of Candlepower per Unit of Discharge Length for Direct Current, UHP Xenon Lamps on the Discharge Power.

Solid Line - Average Value of Experimental Data

1- kw/cm; 2- candlepower/cm

$$B/B_{ц} = 1 - 0,5\,(l/b_0)^2. \qquad (7)$$

The parabola is shown in Figure 4 by the solid line.

We are planning to continue this study, investigating the brightness distribution in other transverse cross-sections of a xenon arc.

Dependence of Candlepower on Power.

In (Ref. 5) it is affirmed that the candlepower is related to the power by the power dependence $I_{\perp} \sim W^s$, where s = 1.6. It is also affirmed that at powers of 1 kw/cm $I_\perp$, which is expressed by the curve $I_\perp = \Phi(W)$, begins to tend toward saturation.

The results which we obtained do not confirm this dependence of candlepower on power, although the observations were carried out up to a power on the order of 6 kw/cm. We observed a linear dependence for all values of the pressure and distance between the electrodes in the lamp. Figure 5 /9 plots the experimental values for candlepower as a function of power. The solid line is the average of these values. The scatter of the experimental points is intensified for large powers as the result of a reduction in accuracy due to the use of an absorbing filter. The deviations of the experimental points from the average line lie within the limits of measurement accuracy. The inclination of the line determines the proportionality coefficient in the expression for the dependence of the candlepower on power

$$I_\perp = 5{,}7\, W_p, \tag{8}$$

where $I_\perp$ is given in kilocandles, and W_p is given in kilowatts.

Attention should be called to the agreement between the proportionality coefficient in expression (8) and the proportionality coefficient in (3) for the discharge center. It thus follows that for the same discharge power the lamp candlepower is related to the central brightness by the following relationship

$$I_\perp = B_ц d_0^2. \tag{9}$$

Volt Ampere Characteristics of Xenon Lamps.

The voltage decrease in a xenon lamp follows from the voltage decreases at the leads, in the positive column, in the discharge sections adjacent to the electrodes, and also follows from the total voltage decrease across the electrodes.

The voltage decrease at the leads is small and, although it increases with a current increase, it may be disregarded in the first approximation. The total voltage decrease at the electrodes depends slightly on the current, and for current values of several tens of amperes and more, it may be assumed that its power is constant and is 9 - 10 v (Ref. 6). Thus, the volt ampere characteristics are entirely determined by the dependence of the voltage decrease in the positive column and the discharge sections close to the electrodes on the current power.

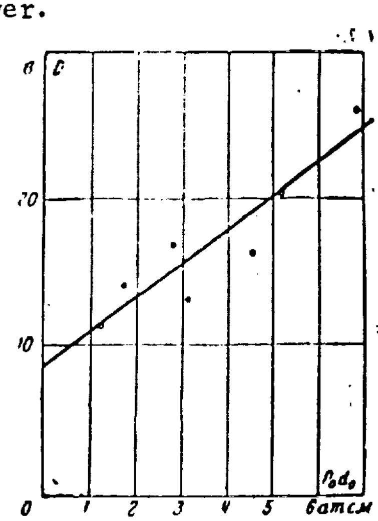

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Figure 6.

Dependence of Coefficient D in Formula (10) on the Product P_0d_0. 1- tech. atm.

Several studies - for example, (Ref. 5) - have investigated the voltage gradient in a positive discharge column in xenon. However, its dependence was determined within a general framework for only a limited region of a change in the current power (up to approximately 40 a). Still less is known about the voltage gradient in the cathode spot. Therefore, it is difficult to predict the nature of voltage dependence on current force in a lamp on the basis of existing data.

We studied the volt ampere characteristics of direct current, xenon lamps, when the lamps changed between 20 - 200 a. In this range, the volt ampere characteristics had a linear nature, and their inclination had a clearly-expressed dependence on distance between electrodes and lamp pressure. In general form, the volt ampere characteristics of a direct current, xenon lamp may be written as follows

$$U = Ei + D, \tag{10}$$

where E and D are the coefficients depending on d_0 and P_0.

In order to determine these coefficients, their values were compiled as a function of the product $P_0 d_0$. As may be seen from Figures 6 and 7, these points lie on straight lines. These formulas may thus be expressed by the following formulas

$$E = 0{,}03 P_0\,[\mathrm{atm}] \cdot d_0\,[cм] + 0{,}05; \tag{11}$$

$$D = 2{,}33 P_0\,[\mathrm{atm}] \cdot d_0\,[cм] + 8{,}6. \tag{12}$$

Method of Calculating Direct Current, Xenon Lamps.

Based on the empirical patterns obtained, we may formulate a method for determining the main electric and light parameters of UHP, direct current xenon lamps. This method may be applied within the limits in which these patterns remain in force.

Let us investigate two computational cases which are frequently encountered in practice: (a) the distance between electrodes and the lamp power are given, and it is necessary to determine its regime and light characteristics; (b) brightness in the discharge center (or at any other point /10 on the discharge axis) and distance between electrodes are given, and it is necessary to determine the lamp power, its regime, and the remaining light parameters.

In the first case, the following computational sequence is applied:

1. The magnitude of the initial pressure P_0 is selected on the basis of explosion-proof features of the lamp, and the coefficients E and D are computed according to formulas (11) and (12).

2. The operational current power is computed according to the formula

$$i=\frac{-D+\sqrt{D^2+4EW}}{2E}.$$

This formula is obtained, if U, according to formula (10), is substituted in the expression for the lamp power $W = iU$, and if it is solved with respect to i.

3. The discharge power is determined

$$W_p=W-10i,$$

where $10i$ are the electrode losses according to (Ref. 6).

4. The brightness is determined at the discharge center according to formula (3), and the brightness distribution is determined along the discharge axis according to formula (4).

5. The candlepower is determined according to formula (8). The light flux Φ in xenon lamps equals the candlepower multiplied by the coefficient 10 (Ref. 5). The light supply η is tentatively determined on the basis of the light flux, which is found in this way, and the specific lamp power.

6. The arc halfwidth in the discharge center is calculated from formula (5), and the brightness distribution across the discharge is computed according to formula (7).

In the second case, the computational sequence is as follows. The discharge power, which would provide a given brightness at the discharge center for a given distance between the electrodes, is determined according to formula

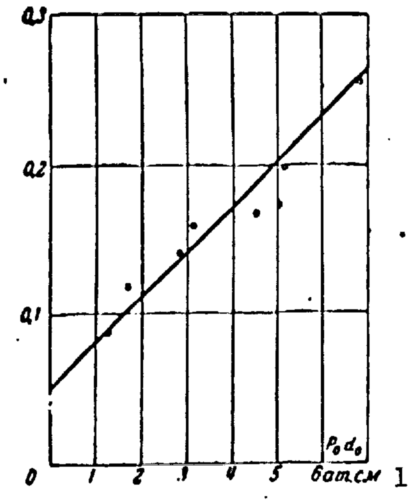

Figure 7.

Dependence of Coefficient E in Formula (10) on the Product $P_0 d_0$. 1- tech. atm.

(3). The current power is found from the following expression

$$i = \frac{-(D-10) + \sqrt{(D-10)^2 + 4EW_p}}{2E},$$

in which the lamp power is replaced by the discharge power. All the subsequent computations are performed similarly to the preceding case.

The computational accuracy is primarily determined by the accuracy of the given empirical formulas. Formulas (1), (3), (10) provide an accuracy of about 10 - 15%, and formulas (5), (7), (8) provide an accuracy of about 15 - 20%.

The experimental results presented by the author in this article, as well as their generalization, are included in an article investigating high current discharge in xenon, carried out at the Moscow Electric Lamp Factory, under the guidance of S. V. Borisov and D. A. Goukhberg, to whom the author would like to express his appreciation for giving their attention to this article.

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